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Modelling Bus Lost Time: An Additional Parameter Influencing Bus Dwell Time and Station Platform Capacity at a BRT Station Platform

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ABSTRACT
The common approach to estimate bus dwell time at a BRT station is to apply the traditional dwell time methodology derived for suburban bus stops. In spite of being sensitive to boarding and alighting passenger numbers and to some extent towards fare collection media, these traditional dwell time models do not account for the platform crowding. Moreover, they fall short in accounting for the effects of passenger/s walking along a relatively longer BRT platform. Using the experience from Brisbane busway (BRT) stations, a new variable, *Bus Lost Time* (*LT*), is introduced in traditional dwell time model. The bus lost time variable captures the impact of passenger walking and platform crowding on bus dwell time. These are two characteristics which differentiate a BRT station from a bus stop. This paper reports the development of a methodology to estimate bus lost time experienced by buses at a BRT platform. Results were compared with the Transit Capacity and Quality of Service Manual (TCQSM) approach of dwell time and station capacity estimation. When the bus lost time was used in dwell time calculations it was found that the BRT station platform capacity reduced by 10.1%.

Keywords: BRT, loading area, dwell time, lost time, passenger walking.

INTRODUCTION
Bus lost time, defined in this paper, is a component of bus dwell time which has not been considered by previous researchers. The traditional approach of estimating bus dwell time at a stop, which is based on the number of passengers alighting and boarding (*1*,*2*,*3*,*4*) is considered to be suitable for analysis of suburban stops with one or two designated bus loading areas in series. The Transit Capacity and Quality of Service Manual (TCQSM) procedure (*2*) for analysis of Bus Rapid Transit (BRT) station capacity has maintained the traditional approach of estimating bus dwell time of a bus stop. However, in this body of research the TCQSM procedure for a BRT station has been shown to yield different dwell time and station platform capacity estimates than those measured at a BRT station with multiple linear loading areas (*5*,*6*).

Unlike the typical, shorter suburban bus stop, BRT platforms can be quite long, with three or four loading areas in series, such that the time for passenger/s to walk to the bus entry door can add a substantial component to the dwell time. Since conventional dwell time models do not explicitly account for the passenger's walking time to the bus entry door, in particular for the first passenger, they may under-estimate actual dwell times. Hence the traditional approach needs to be modified to suit the operation of a BRT station platform.

Passenger boarding activities at a BRT station can be divided into four distinct parts:- the first part is the initial reaction of hailing when the passenger first sees the desired bus. The second part consists of walking to the bus entry door. The third part consists of queuing at the entry door. The fourth part is boarding the bus.

Previous work in this body of research (*5*) argued that the first and second parts comprise a time referred to as the *passenger – bus interface* stage, which commences when the passenger first identifies their desired bus and hails its driver and/or commences walking towards stopping location anticipated by the passenger. Similarly, the driver of the bus, after seeing the hailing passenger/s, prepares to stop at the most downstream loading area on the platform that is empty. During this course of action, both the bus driver and the passenger act independently but anticipate each other. It has been observed in this research, at a BRT station typically a stopped bus has to wait in its loading area for the first and any subsequent passenger/s to arrive at entry door and board. This waiting time for bus, between when the bus comes to stop in its loading area and when the first passenger boards, is defined as '*bus lost time*'. This lost time inflates the bus's dwell time in its loading area at the platform.

Previous work in this body of research (*5*) also argued that the third and fourth parts comprise the *passenger – bus interaction* stage. However, when only one or two passengers boarding the bus, queuing may not occur and this stage consists only of boarding. Any alighting of passengers through the front door generally occurs prior to, and therefore in series to, boarding. Any alighting of passengers through the rear door generally occurs in parallel to the above. In either case, passenger alighting occurs within the *passenger – bus interaction* stage. Traditional dwell time models (*1,2,3*) imply that alighting and boarding occur in series, and presume to accounts only for those alighting through the front door. Any passengers alighting through the rear door are neglected in the standard model, as their activity occurs in parallel to the front door activity, which is implied to be time-critical (*2,3*).

The bus lost time at a BRT station with multiple linear loading areas is a new concept which has been not explored in the past literature. The objective of this paper is to evaluate the bus lost time at a BRT station and define the descriptive statistics of bus lost time which can be applied at various aspects of BRT design and analysis. For information regarding the development of this concept, please refer to the previous publications from this body of research (*5,7*). It is noted that this research is currently limited to the case where boarding is critical. Further work is required to evaluate the validity of the standard model for the majority alighting station on a BRT platform.

The next section describes the study station and data collection procedure used. Section three explains the bus lost time and associated variables. Section four presents the approach for estimating bus lost time and presents probability distribution curves developed in this broader study for bus lost time. Section five presents a modified bus dwell time model for a BRT station. A sample application is given in section six and section seven discusses the findings. The last section presents conclusions drawn from the results and future research scope.

DATA COLLECTION

The data used in this research was collected through video recording at the Mater Hill Busway station, Brisbane, Australia. The study station is the fourth station from the Brisbane central business district on the 16 km South East Busway (BRT) corridor. Mater Hill busway station now has three signed and striped loading areas on its outbound platform as shown in Figure 1. (Note that in Australia, vehicles are driven on the left side on the roadway). Infrequently some bus operators pull up very close to the dwelling bus ahead of them, thereby creating a transient fourth loading area. This was more prevalent prior to the signing and striping of three loading areas, which occurred midway through this overall project. Station users include school and university students, hospital employees, patients and visitors, and employees of surrounding businesses. Importantly, this station is located inwards of the confluence of four common-lines; the mainline South East Busway, the Woolloongabba spur common-line, the Pacific Motorway access ramps common-line, and the Annerley Road common-line. Hence, there is also a considerable level of passenger interchange at this station.

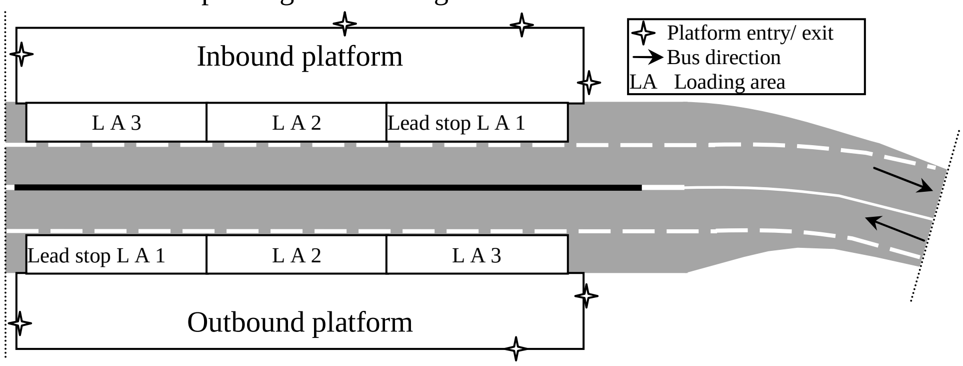


FIGURE 1 Configuration of Mater hill busway station.

The commonest bus on Brisbane's busway system is two-door rigid buses, followed for a small but growing fleet of two-door articulated buses, and a very small number of largely single-door rigid coaches. In Brisbane, a passenger can only board the bus through its front door. Alighting from a bus is permitted from both doors; front and rear, but passengers are encouraged to use the rear door. Video footage was captured at a similar time of year in three successive years; March 2007, March 2008 and April 2009. This was to ensure that the data collection was free from data noise due to school or university vacation periods, public holidays etc. Each video data set was captured on a Wednesday, being a typical midweek day. These data collection activities were carried out with the assistance of the Translink Transit Authority's Busway Operations Centre in Brisbane. The passengers on the platform were unaffected by the video data collection as permanent security cameras were used. These cameras, mounted on the ceiling of the busway platform awning, record the movements of passengers on the platform on a 24hr / 7 day basis.

Three distinct time periods of the analysis day were subsequently analysed in a laboratory environment at QUT to obtain three distinct groups of variables (Table 1); the morning off-peak period 10:00 am to 11:00 am; the afternoon peak period 3:00 pm to 4:00 pm (referred as peak); and the evening off peak period 7:00 pm to 8:00 pm. The morning peak period was not considered, because it is negligible for boarding passengers. However, the morning peak for the study station occurs on the inbound platform and comprises of heavy passenger alightings. The alighting passengers do not cause lost time to their buses, but do cause dwell time.

For each bus servicing at the platform, its first boarding passenger was tracked from the time when they first reacted to the bus until the time they boarded that bus. A passenger is considered as boarded when at least one of their feet is on the bus floor. In addition, for each one hour time period, 50 passengers randomly selected from the platform crowd were observed, from the time when they first reacted to their desired bus until the time when they boarded their bus. The methodology to extract variables was designed specifically to capture bus lost times occurring at the BRT station platform.

TABLE 1 Summary of Variables

Bus	Passenger	Platform
• Service loading area	• Initial reaction / hailing time	• Number of passenger waiting on the platform
• Stopping time	• Boarding time	
• Door opening	• Number of passenger encountered en route to bus entry door	

BUS LOST TIME

In order to accurately determine lost time for buses it is necessary to understand its complex and dynamic relationship with passenger walking, bus stopping, and crowd density. The relationship is complex because the passenger walking and bus stoppage are two entirely independent progressions but passenger walking is cautious of bus stoppage. Since walking time is dependent on distance to cover and obstructions en route, the relationship is dynamic as it changes with time and crowd density.

In the absence of any prior research on bus lost time it is advantageous here to define bus lost time and its associated variables graphically.

Time- space diagram

Observations made at the study BRT station indicate that only the duration of passenger – bus interface of the first passenger impacted bus dwell time. Because of the simultaneous interfaces of all boarding passengers with the desired bus, all boarding passengers except the first boarding passenger overlap their respective passenger – bus interface duration with that of first passenger's interface. In addition to this, some part of the first passenger's interface duration overlaps with the time taken by the bus to reach the loading area. The above observations can be better understood using the time-space diagram shown in Figure 2. The distance in space along the line of the platform is represented on the Y axis and the time is represented on the X axis. The X – X axis, in space, represents the location of the bus entry door. P_1, P_2, … P_n are the position of the first, second and n^{th} passenger at time t_0 when they first observe their desired bus, B. In this case the dwell time for the bus is equal to sum of the lost time (*LT*), passenger – bus interaction (*IA*) and the door opening and closing time (t_{oc}). This paper defines '*lost time*' as the time lapse between when the bus comes to rest at its loading area and the time of boarding of the first passenger. Note that portions on the *passenger – bus interface* duration of the 2nd … nth passenger occur during the *passenger – bus interaction* period, *IA*. The variables in Figure 2 are described below:

DT = Bus dwell time
LT = Bus lost time
t_0 = Time when passenger(s) first see the desired bus (say at point B in space)
IA = Duration of passenger – bus interaction
$P_1, P_2,.., P_n$ = Location of 1st, 2nd,…, nth passenger in the space at time t_0. $IF_1, IF_2,\ldots,IF_n$ represent their respective passenger – bus interface durations.
t_{oc} = Door opening and closing time

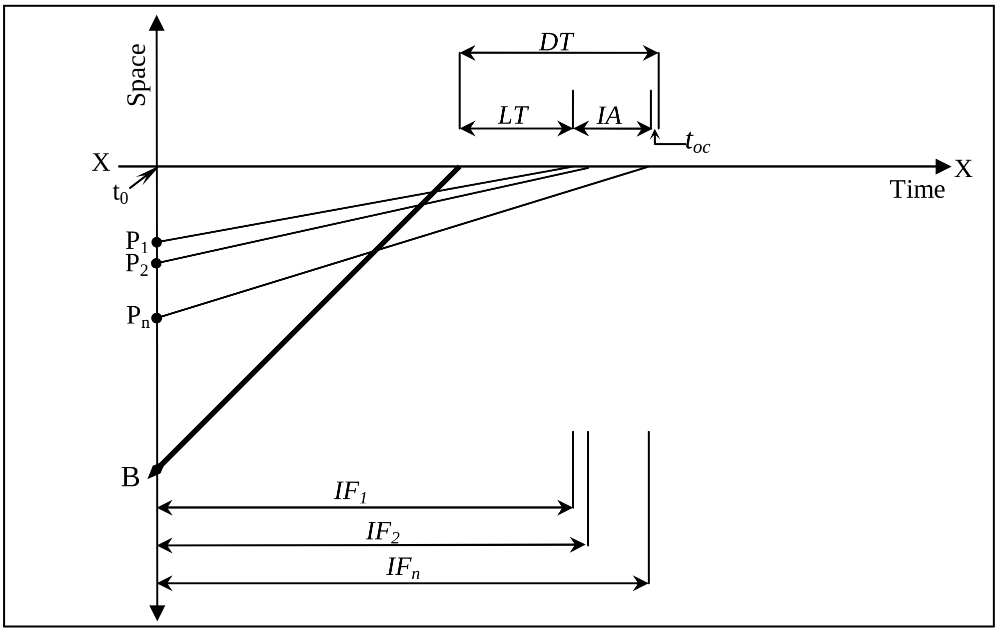


FIGURE 2 Time – space diagram.

APPROACH TO ESTIMATE LOST TIME

This methodology pertains to bus lost time at a BRT station with multiple linear loading areas. The bus lost time is studied as a function of loading area i.e. the walking distance and crowd i.e. passenger/s obstructing the walking.

Crowding at the platform has a manifold effect on the platform operation. Not only does it reduce manoeuvring capabilities of passengers, but also causes occlusion to approaching buses. This results in increased passenger reaction time upon the arrival of their expected bus. Additionally, the crowd acts as an obstruction in the walking path of the passenger. The passenger is no longer able to use the straight line path to bus entry door, but has to use a zigzag path. It causes a reduction in walking speed as well as an increase in walking distance. This delays the passenger arrival at the bus entry door and ultimately results in increase in lost time for the bus. For this study the crowd at the platform is measured as the average number of people waiting on the platform in a 15 minute interval. Crowd density was not used as a variable because it not consistent across the platform. For instance, the crowd density at the shaded area (Figure 3) under low crowd conditions can be same as that of the entire platform area under high crowd condition. Therefore use of density for crowd may not properly reflect the true crowd levels of peak and off peak periods.

Moreover, loading area is static in space but the passenger is not. The passenger may chance the waiting position due to the influence of the crowd. Hence the walking distance for the passenger is subject to their waiting position on the platform relative to the loading area. It is therefore important to first study the behavioural pattern of passengers on the platform in selecting their waiting position on the platform.

Passenger behavior while waiting

The arrival procedure at the study station, in fact at all stations on the Brisbane busway network, is such that an arriving bus should use the loading area of the platform at or closest to the lead loading area. This means that if all the loading areas are empty the bus should use loading area 1 to provide service to passenger/s. Only if the front loading area is occupied then the next in line loading area should be used. This created relatively higher chances that a bus would use loading areas 1 and 2 over loading area 3. This leads to passengers on the platform waiting between the middle of lead loading area (loading area 1) and loading area 2 for their desired bus (Figure 3).

The distance between the bus door on loading area 2 and shaded area centroid y-y is less than the distance between the bus door on loading area 1 and the shaded area centroid (Figure 3). Therefore, in the best case scenario, the lost time for any bus would be lowest when it uses the loading area 2 for servicing. As the crowd at the platform increases, the additional passengers first spread toward the left side of the shaded area and later sprawl to the left of the shaded area. However, passengers outside of the shaded area will quickly move into the shaded area whenever a space becomes available. For simplicity, we can use this shaded area for referencing purposes.

Using centroid of the shaded area i.e. y-y line, the passenger walking to loading area 1 walks nearly in the direction of the approaching bus to the loading area 1. In contrast, a passenger walking to loading area 3 walks in the direction opposite of approaching bus to the loading area 3. These directional differences between passenger and bus alter their interface and subsequently the lost time for buses on these loading areas. Walking in the opposite direction of the approaching bus reduces the overlapping component of the passenger – bus interface, causing higher lost time. This is because the bus needs to cover less distance to reach at the loading area. In contrast, walking in the same direction as the approaching bus slightly increases the overlapping component of the passenger – bus interface and could cause slight reduction in lost time.

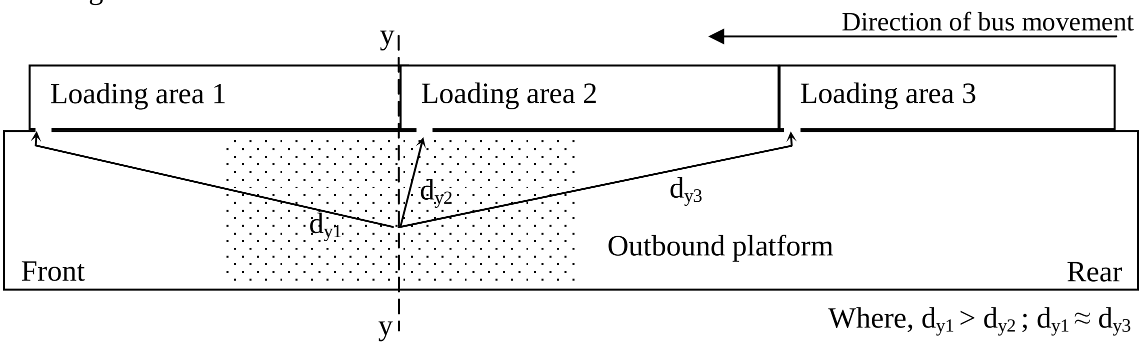


FIGURE 3 Distance to loading areas from the waiting area on the platform.

Bus lost time variation

In the light of the crowd behaviour explained above, the bus lost time for individual loading areas was analysed against the platform crowd level. Figure 4 shows that they have dissimilar changes in their lost time as the crowd level at platform increases. For loading area 1 the lost time initially got increased with the increase in crowd level. However, with further increase in crowd the average lost time got decreased. The initial increment in lost time may be because of the crowd have acted as obstruction in the path to bus entry door for loading area 1. When passengers moved into the area left of the shaded area (Figure 3) it resulted in drop in bus lost time for loading area 1. Whereas the relatively obstruction free path to loading area 3 resulted in less lost time for buses on loading area 3 than loading area 1 under the low crowd level condition.

On the contradictory, the average lost time for buses using loading area 2 decreased initially but later increased back. This is reasonable because of the behaviour of passengers in selecting the area adjacent to loading area 2 (shaded area in Figure 3). They have shortest distance to cover to reach the loading area 2. However, as more passengers tries to fit into this limited space they increases the obstructions to walking. This resulted in lost time again increased back under high crowd level.

Loading area 3 has shown a steady increase in the bus lost time with platform crowd. This is reasonable because of the two main reasons. First, the increase in obstruction with increase in crowd level and second, the majority of passengers require to walk in the direction opposite to the approaching bus.

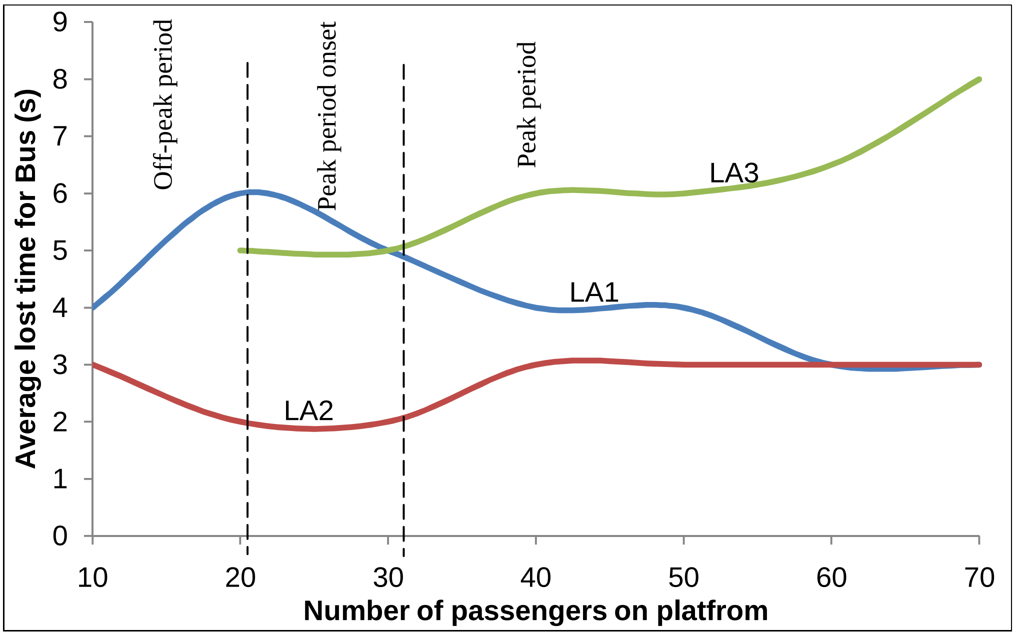


FIGURE 4 Variation in bus lost times over platform crowd.

Probability distribution curve for bus lost time

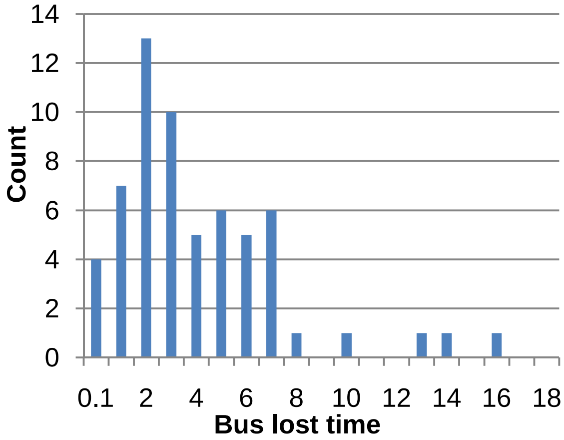
To make these results applicable on a broad scale, probability distributions were fitted to the observed bus lost time data sets. As found in the previous section, the loading areas' dependency of bus lost times, separate probability curves are fitted to each loading area and separately for peak and off-peak period.

As a first step of the analysis, the bus lost time frequency distribution was plotted. The resulting histograms indicate that the bus lost time for none of the loading areas is normally distributed (Figure 5). The histograms were positive skewed, which suggested that a lognormal distribution or Weibull distribution could be fitted (*8*). In order to fit the lognormal distribution, the natural logs of the observed data sets were taken and then the histogram was plotted again. The histograms of the transformed data sets were checked for normality. The normal probability plot technique was used to assess the normality of the data sets (Figure 6). If the resulting probability plot is linear then the test for normality was successful. In this case, the normal probability plot for natural logarithm of lost time data showed the linearity, so it can be concluded that the bus lost time is log-normally distributed. The descriptive statistics for each loading area is provided in Table 2. The bus lost time across all three loading areas was found to have lognormal distribution with natural logarithm of bus lost times normally distributed.

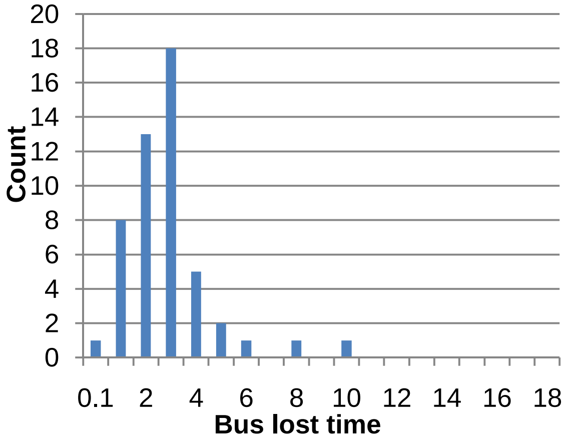
Due to insufficient observation during the off peak operation of loading area 3 the statistical analysis was not carried out for it. Figure 7 provides the bus lost time probability distribution function (PDF) for the lognormal distribution curves for each loading area for peak and off peak time periods. Figure 8 provides the cumulative distribution function (CDF) of bus lost times. Table 3 gives the mean, mode, median and 85th percentile values of bus lost time for all three loading areas.

TABLE 2 Descriptive Statistics for Curve Fitting (Afternoon Peak Period)

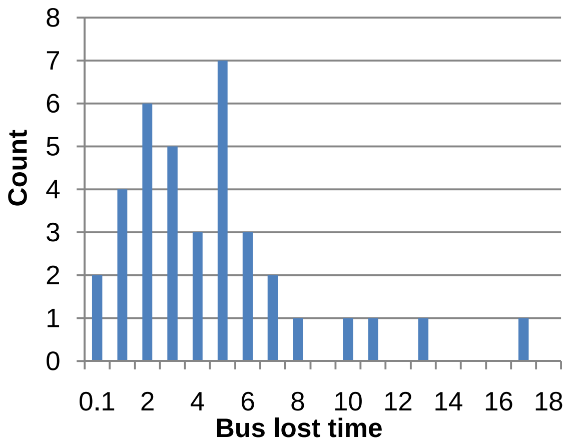
Description	Loading area 1		Loading area 2		Loading area 3	
	Raw data (x)	Log[x]	Raw data (x)	Log[x]	Raw data (x)	Log[x]
Count	61	61	50	50	38	38
Mean	4.07	1.10	2.85	0.90	4.90	1.23
Median	3.00	1.10	3.00	1.00	4.00	1.38
Std dev.	3.24	0.84	1.73	0.58	3.92	0.87
Skewness	1.69	-0.36	2.02	-0.31	1.52	-0.44
Kurtosis	3.50	-0.23	6.14	0.58	2.22	-0.09



a) Loading area 1



b) Loading area 2



c) Loading area 3

FIGURE 5 Afternoon peak period bus lost time histogram.

From the peak period curves (Figure 7) for all the three loading areas, it was noted that all three loading areas have nearly same probabilities of experiencing a lost time of 4.3s. However loading area 2 has a higher probability of experiencing lost time of less than 4.3s. Whereas, the loading area 3, relatively to loading area 1 and 2, has lesser chances of experiencing a lost time less than 4.3 sec. On the contrary, the probability of loading area 3 getting a lost time larger than 4.3s is relatively higher in comparison to loading area 1 and 2.

The comparison between peak and off peak curves shows that the off peak curve for loading area 1 is shifted toward right relative to the peak period curve. This shift indicates that loading area 1 is more likely to have a higher lost time during a low crowd situation. Similarly, for loading area 2 the likelihood of higher lost time increases during off peak period operation. These results are consistent with observations in Figure 4 and passenger behaviours explained earlier.

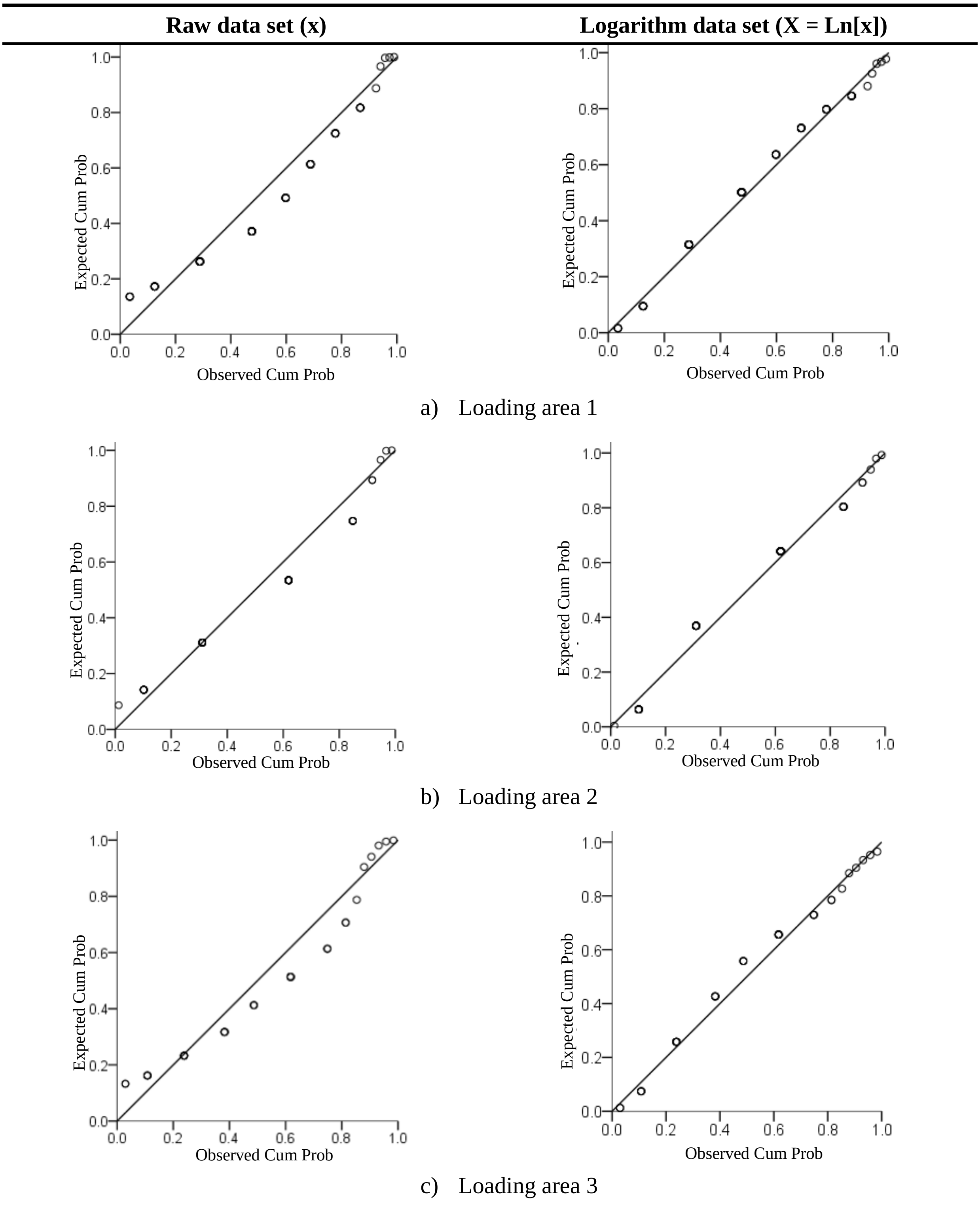


FIGURE 6: Test of normality using normal probability plots.

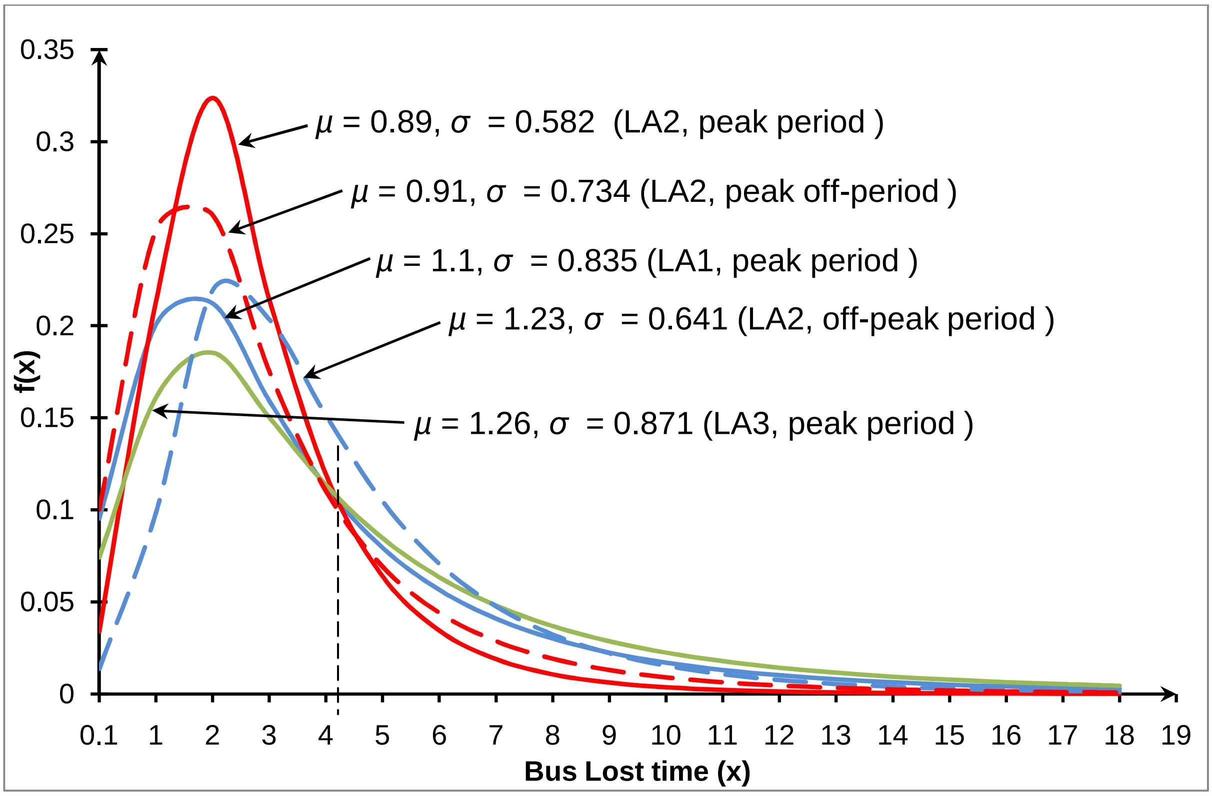


FIGURE 7: Bus lost time probability distribution curves.

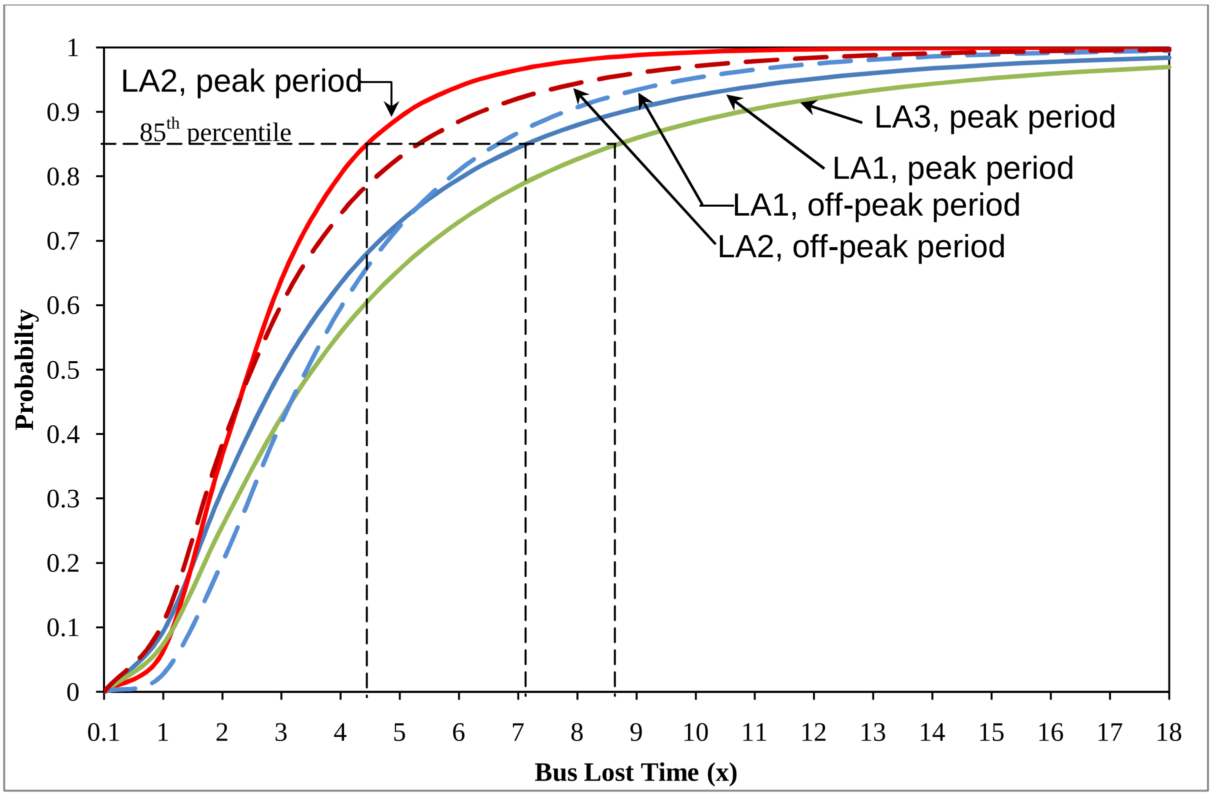


FIGURE 8: Bus lost time cumulative distribution curves.
Note: LA = Loading area; OP = Off-peak

The CDF highlights the effect on bus lost times due to difference in direction of motion of a passenger and approaching bus. For a given probability, the lost time for loading area 3 is always higher than that for loading area 1. Theoretically the CDF for the loading area 1 and 3 should overlap or be near eachother, because the walking distance to both loading areas is nearly the same from the shaded area. However, the CDF of loading area 3 is right shifted with respect to loading area 1. This is because a passenger requires walking in the direction opposite to the approaching bus to loading area 3, as against the same directional motional for loading area 1. This directional discrepancy resulted in a lesser slope to the CDF for loading area 3 compared to loading area 1.

TABLE 3 Descriptive Characteristics of Busway Station Bus Lost Times (Peak period)

	Loading area 1	Loading area 2	Loading area 3
Mode of lost time	1.6	2.0	2.0
Median lost time	3.0	2.4	3.5
Mean lost time	**4.3**	**3.1**	**5.2**
85^{th} percentile lost time	7.2	4.5	8.7

BRT STATION DWELL TIME MODEL

Bus lost time occurs prior to start of actual boarding but after the bus stoppage. As explained in Figure 2, the lost time is additive to the convention dwell time. Equation 1 provides the modified bus dwell time model for dwell time estimation at a BRT station with multiple linear loading areas.

$$DT_n = P_b t_b + P_a t_a + t_{oc} + LT_n \qquad \textbf{Equation 1}$$

Where,

DT_n	=	Bus dwell time at n^{th} loading area
$P_b;\ P_a$	=	Number of passenger boarding and alighting respectively
$t_b;\ t_a$	=	Service time per boarding and alighting passenger respectively (s)
t_{oc}	=	Bus door opening and closing time (s)
LT_n	=	Bus lost time at n^{th} loading area (s)

BRT LOADING AREA CAPACITY MODEL

The platform capacity of a BRT station is determined by the capacity of individual loading areas. The modified loading area capacity equation is derived as below.

$$B_{sn} = \frac{3600\,(g/c)}{t_c + DT_n(g/c) + zC_v(DT_n - LT_n)} \qquad \textbf{Equation 2}$$

Where,

B_{sn}	=	Capacity of n^{th} loading area (bus/hr)
3600	=	Number of seconds in 1 hour
g/c	=	Green time ratio
t_c	=	Clearance time (s)
z	=	Standard normal variable corresponding to a desired failure rate
C_v	=	Coefficient of variation of dwell time

Note that the Equation 2 does not use bus lost time to increment dwell time to consider failure rate and passenger demand fluctuations. It is not necessary here as the design bus lost time is determined based on the acceptable failure rate. Moreover, the bus lost time at a BRT station platform depends on the bus and its first boarding passenger and therefore the bus lost time would not fluctuate with passenger demand between buses and between routes.

SAMPLE APPLICATION

The significance of the bus lost time is demonstrated by estimating the station capacity for an example BRT station. The Transit Capacity and Quality of Service Manual (*2*) methodology was used for base calculations and the results were compared with the modified method considering bus lost time. For this purpose, a boarding load of 7 passengers per bus with boarding service time of 4s and no alighting load was considered. The estimation was done with assume failure rate of 7.5%, 60% coefficient of variation, 3 linear loading areas, g/c of 1, 10s clearance time, and door opening and closing time of 2s. The 85th percentile of bus lost time was used for revised capacity design (Figure 8). Table 4 shows the comparison of the results from the two methods. The modified method which considered the bus lost time indicated 10.1% reduction in station capacity compared to station capacity obtained from TCQSM method.

TABLE 4 Example Demonstration

Method	Bus dwell time			Station Capacity
	Loading area 1	Loading area 2	Loading area 3	
TCQSM (without bus lost time)	30s	30s	30s	143 bus/hr
Revised (with bus lost time)	37.2s	34.5s	38.7s	130 bus/hr
% change	+24.0%	+13.4%	+29.0%	-10.1%

IMPLICATIONS OF PROPOSED METHODOLOGY

The bus lost time is a loading area specific parameter and reflects the requirement of passenger walking on the long BRT station platform to reach at bus entry door. Additionally, it also accounts the impact of changing platform crowd on the bus dwell times. Unlike the conventional bus stop dwell time models, which estimate a blanket dwell time value for buses across all loading areas, the suggested BRT station dwell time model estimates different dwell time values for each specific loading area depending on the prevailing operation condition of the BRT platform. The understanding of bus lost time can be applied in improving the methodology of busway station bus capacity analysis. Furthermore, the probability models, presented in this paper, can be used to develop a micro-simulation based model to study busway station operation.

The bus lost time is not sensitive to the variation in number of boarding passengers per bus. As long as at least one passenger boards the bus, the bus would have a set amount of lost time. The number of boarding passengers only affects the total boarding time. By separating the boarding time and lost time, better dwell time estimation can be achieved. Hence, this new methodology for estimating bus dwell time at busway station can help transit planners in improving the scheduling of service timetable and in turn could greatly enhance the travel time reliability.

CONCLUSIONS

The comparison of station capacities showed that the BRT station capacity reduced by 10.1% when bus lost times was considered. This shows that bus lost time affects the BRT station capacity. Therefore it is absolutely necessary to consider bus lost time in dwell time estimation which will then be used in designing the BRT station capacity.

This paper suggests the lognormal probability distribution curves for estimation of bus lost time for each of three linear loading areas. It would be interesting to see the impact on lost time distribution if an additional fourth loading area is added to the current set of three. The bus lost time estimation approach need to be refined with the help of more case studies to generalise it for a wide range of BRT operations.

Identifying the variables governing the operation of BRT station and developing a methodology to estimate the station capacities accurately is absolutely necessary to explore the BRT system to its full potential. Bus lost time at platform is one such variable which manipulates the operational capacity of BRT station. In this paper we demonstrated the bus lost time, its characteristics, and its effects on the dwell time, and on final station bus capacity.

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